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The effects of temperature on short-term mortality risk in Kuwait: A time-series analysis

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ABSTRACT

Background: In light of climate change, health risks are expected to be exacerbated by extreme temperatures. Many studies showed that high and low ambient temperatures are associated with increased short-term mortality risk, but little is known about these risks in Kuwait and the Gulf Region.
Objective: To examine the dose-response relationship between 24-h average ambient temperatures and daily mortality risk in Kuwait.
Methods: We gathered mortality and meteorological data from 2010 to 2016 in Kuwait. We did a time-series analysis using a negative binomial distribution, and studied the lag effects of temperature with distributed lag non-linear models.
Results: A total of 33,574 all-cause non-accidental deaths were analyzed. The relationship was shown to be non-linear. Overall relative risks of death comparing the 1st percentile (10.9 °C) and the 99th percentile (42.7 °C) to the optimum temperature were 1.67 (1.02–2.73), and 1.65 (1.09–2.48), respectively. Cold effects persisted for 9 days, while the effects of hot temperatures were the highest at lag 0 and only persisted for a week. Adjusting for PM_{10} and ozone did not change the temperature-mortality estimates.
Conclusion: Our findings show evidence that there is a statistically significant positive association between temperature extremes and mortality in Kuwait. The evidence has significant implications in assessing climate vulnerability and provides insight into environmental challenges in an inherently hot and arid region.

1. Background

The relationship between temperatures and short-term risks of mortality is well studied and described in the literature (Basu and Samet, 2002; Ye et al., 2012; Gasparrini et al., 2015). This area of epidemiological research has gained a lot of attention in response to climate change and extreme weather events (Gasparrini et al., 2017). The Intergovernmental Panel on Climate Change (IPCC) fifth assessment report projected that heatwaves are expected to increase over the next decade in terms of their intensity, and spatial extent (IPCC, 2013).

Exploring the relationship between deaths and ambient temperatures can be challenging due to possible misclassifications of death causes (Hajat and Kosatsky, 2009). Heat or cold exposure can physiologically exacerbate medical conditions leading to death, other than direct causes like hypothermia, hyperthermia or heat stroke. In general, temperature-related deaths tend to be underestimated (Shen et al., 1998). Epidemiological studies often used non-accidental all-cause mortality data to overcome this misclassification (Zanobetti and Schwartz, 2008; Gasparrini et al., 2015).

Determining the shape of the relationship will help to address policy-relevant questions, such as assessing the public health burden of ambient temperatures and implementing heat-warning systems. Temperature and mortality dose-response relationships tend to take J-, V- or U-shaped curves (Anderson and Bell, 2009; Curriero et al., 2002). Mortality is typically high with extremely low temperatures, then it decreases at the optimum temperatures (minimum mortality), before starting to climb again with extremely high temperatures. U-shaped curves have a threshold effect with more pronounced effects at temperature extremes compared to the slopes of V-shaped curves.

Kuwait has a hyper-arid and desert climate. The country's geographical location makes it vulnerable to a number of climate change health impacts including increased frequency of extreme temperatures (WHO, 2015). Although regional projection models assessing heat-mortality are discussed in the literature (Honda et al., 2014; Huber

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et al., 2017; Ahmadalipour and Moradkhani, 2018), studies utilising country-specific temperature-mortality data in Kuwait and even the Middle Eastern and Gulf countries are scarce. Douglas et al. (1991) and Al-Rifaia et al. (2011) analyzed monthly counts of deaths in Kuwait to detect patterns of seasonal mortality. To the best of our knowledge, no specific published studies have previously characterized the temperature and daily mortality dose-response relationship in Kuwait. In light of rising global temperatures, this study aims to estimate the effects of ambient temperatures on the daily counts of death in an inherently hot environment.

2. Methods and materials

2.1. Geography and climate

Kuwait is located on the corner of the eastern coast of the Arabian Peninsula (Fig. 1). It is a relatively small country with a population of 4 million people. During its long summer months, the temperature typically rises above 40 °C which is overshadowed by dramatic dust storms. From mid-August and throughout September, relative humidity levels can exceed 95% with an average annual rainfall of around 116 mm (KEPA, 2012).

2.2. Data

Daily mortality data for seven years in Kuwait from January 1st, 2010 to December 31st, 2016 was obtained from the National Centre for Health Information, Department of Vital Statistics, Ministry of Health, Kuwait. Cause of death was ICD-10 coded (International Classification of Diseases), including all-cause non-accidental deaths (A00-R99) inside Kuwait.

Kuwait Environmental Public Authority (KEPA) regularly monitors meteorological indicators. Collected data from KEPA for the same study period included; 24-h daily average temperatures (°C), and daily average relative humidity (%) from 15 meteorological stations in Kuwait (Fig. 1). Daily averages (arithmetic mean) of meteorological variables were calculated using all available records from all 15 stations. Whenever a particular meteorological station had a missing value, observations from other stations were used to calculate the average value for that day (Tong et al., 2012; Al-Taiar and Thalib, 2014).

To investigate possible confounders, similarly, daily air quality measures were collected from 16 geographically different KEPA stations. Air quality measures were recorded hourly, we obtained 24-h daily averages in each station. We then averaged the obtained readings across all stations for ozone (ppm) and PM_{10} ($\mu g/m^3$) during the same study period.

2.3. Statistical analysis

We studied the association between mean ambient temperature and daily counts of non-accidental mortality. The analysis period covered all seasons and examined the association with both hot and cold temperatures. All relative risk estimates were calculated relative to the optimum temperature of the least risk of mortality. We used distributed lag non-linear models (DLNM) to describe the effect of temperature over time (Armstrong, 2006; Gasparrini et al., 2010) and studied the lag effect of temperature over a 30-day span to account for potential delayed effects (Gasparrini et al., 2010; Goldberg et al., 2011). The relationship was modeled using negative binomial regression to account for overdispersion. Akaike's Information Criterion (AIC) was used to identify the optimal model comparing linear, linear splines, polynomials of degrees 2, 3, 4, and cubic natural splines of 3–7 degrees of freedom for the temperature and lag effects. Using this approach, we

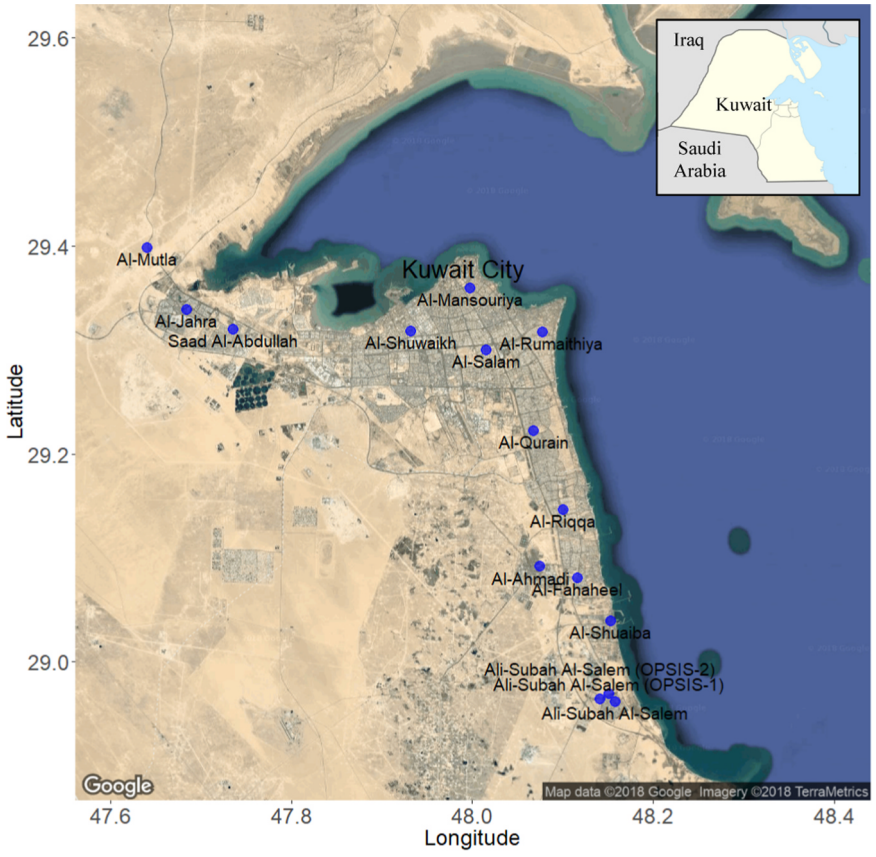

Fig. 1. Locations of temperature recording stations in Kuwait, plotted using Google Maps and the *ggmap* package.

modeled temperature using a polynomial of the fourth degree, and modeled the lag using a cubic natural spline with three degrees of freedom placed equally on the log scale.

Seasonal and sub-seasonal trends in mortality were included in the models using a natural spline function with 7 degrees of freedom per year, and a categorical variable for day of the week. The choice of seasonality terms was adopted from time-series modeling in previous studies (Dominici et al., 2004; Samet et al., 2000; Goldberg et al., 2011). We adjusted our analysis for relative humidity, ozone, and PM10. We used AIC to select the optimal method of modeling these covariates.

The final model was as follows:

$$Log(E[Y_i]) = \alpha + \beta_1 T_{i,l} + \beta_2 NS(Humidity_i, knots = 30, 40) + \beta_3 PM10_i + \beta_4 LS(Ozone_i, knot = 0.02) + \beta_5 NS(Day\ of\ study_i, degrees\ of\ freedom = 48) + \beta_6 DOW_i$$

where $E[Y_i]$ is the expected count of deaths for day i; α is the model intercept; β_1 and β_2 through β_6 are matrix and vectors of regression coefficients, respectively; $T_{i,l}$ is the DLNM cross-basis matrix of temperature and lag (l days); NS is natural spline function; LS is linear spline function; day of study is time in days from January 1st, 2010; and DOW is day of the week.

We conducted sensitivity analyses by modeling temperature using natural splines with 3, 5, and 7 degrees of freedom; varying the degrees of freedom for lag effect; and using natural splines and cross-basis functions to model confounders. We detected significant data entry errors for March 2013 and removed this month from the analysis. We conducted a sensitivity analysis to understand the implications of this choice on our results. All statistical analyses were conducted using R statistical software version 3.4.3 (R Foundation for Statistical Computing, Vienna, Austria) and the *dlnm* package version 2.3.4 (Gasparrini, 2011).

3. Results

3.1. Summary statistics

From January 2010 to December 2016, a total of 33,472 all-cause non-accidental deaths over 2532 time-series of days in Kuwait were analyzed in this study (Table 1). The mean total number of non-accidental deaths was approximately 13 (± 4) deaths/day. Summary statistics of meteorological and air quality variables are also provided in Table 1. The average daily temperature was 27.89 C (± 9.45 C). PM_{10} values showed high variability with a mean of 190.67 μg/m^3 and a standard deviation of 201.19 μg/m^3 . On the other hand, ozone levels had less variability, averaging at 0.023 (± 0.008) ppm.

3.2. Overall temperature effects

The three-dimensional plot (Fig. 2) shows the relationship between daily mean ambient temperatures and daily counts of mortality over all lag days. The entire relationship was non-linear. Both hot and cold temperatures were associated with a high risk of mortality at shorter lags, the effects then decrease with increasing lag times before tipping again as lag days reach 30. Overall, the graph only shows the general pattern of the relationship, meanwhile, the rest of the results (including slices from the 3D plot) will provide more detailed descriptions with the variability around the estimates.

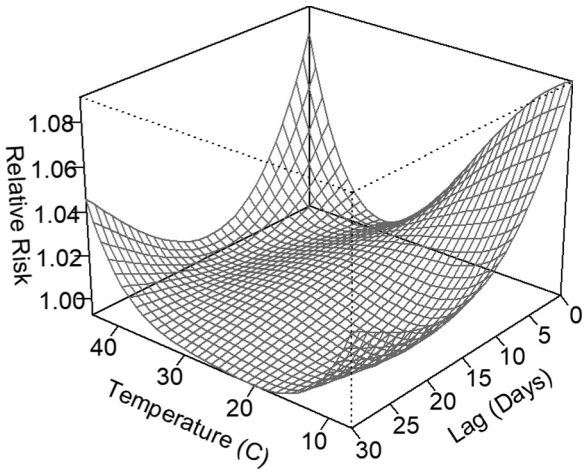

Fig. 2. 3D plot of the relative risk of daily non-accidental mortality vs. daily mean ambient temperature by lag period using DLNM and adjusting for seasonality, relative humidity, PM_{10}, ozone, and day of the week.

Table 2 shows the overall relative risks of death at the 99th (42.7 C), 97.5th (41.6 C), 1st (10.9 C) and 2.5th (12.3 C) percentiles compared to the optimum temperature (34.7 C = 66th percentile) for the cumulative distributive lag model adjusting for air quality variables and day of the week. Using more extreme percentiles was associated with substantially higher relative risks of death. The overall mortality risk comparing the 1st percentile and the 99th percentile relative to the optimum temperature was 1.67 (95% CI, 1.02–2.73), and 1.65 (95% CI, 1.09–2.48), respectively. The inclusion of ozone and PM_{10} into the model attenuated the effects but did not considerably change the regression coefficients. The estimates of cold effects were slightly higher than the hot effects with and without air pollution adjustments. Other modeling techniques of temperature and using cross-basis functions for covariates resulted in similar inferences (Supplementary material). Adding the month of March 2013 to the dataset in the sensitivity analysis did not affect our results.

3.3. Lag effects

The hot effects persisted for the initial 7 days while the cold effects showed significant increases in risk within 0–9 days (Table 3). During these early lag periods the dose-response curve showed that the magnitude of the association between death and extreme temperatures (1st and 99th percentiles) was highest immediately (lag 0) then declined afterwards (Fig. 2). Reaching longer lags showed another increase in the risk of death significantly with hot temperatures (Fig. 3).

Table 1
Descriptive statistics of daily mortality, meteorological and air pollution data for the period from 2010 to 2016 in Kuwait.

Variables[a]	No. of days measured	Mean	SD	Median	IQR	Min	Max
Total Non-Accidental Deaths *(deaths/day)*[b]	2532	13.27	4.12	13	5	1	35
Temperature *(C)*	2532	27. 89	9.45	28.70	17.55	6.86	44.65
PM10 *(microgram/m^3)*	2532	190.67	201.19	127.54	104.38	26.01	2464.62
Relative Humidity *(%)*	2532	37.87	17.14	33.59	27.19	11.12	89.74
Ozone *(ppm)*	2532	0.023	0.0080	0.022	0.017	0.0050	0.090

[a] Temperature, PM10, relative humidity and ozone were computed as 24-h averages.
[b] Total number of deaths over study period = 33,472.

Table 2
Overall relative risks with and without air pollution adjustments for a cumulative distributive lag of 30 days for different heat and cold effects definitions.

	Heat effect[a]				Cold effect[a]			
	99th vs. Optimum[b]		97.5th vs. Optimum[b]		1st vs Optimum[b]		2.5th vs. Optimum[b]	
Pollution Adjustment[c]	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI
Temperature	1.65	1.09–2.48	1.42	1.03–1.95	1.67	1.02–2.73	1.53	0.97–2.40
Temperature & ozone	1.65	1.09–2.48	1.42	1.03–1.94	1.66	1.01– 2.70	1.51	0.96–2.37
Temperature & PM10	1.64	1.09–2.46	1.41	1.02–1.93	1.69	1.03–2.75	1.54	0.98–2.42
Temperature, ozone, & PM10	1.63	1.09–2.46	1.41	1.02–1.93	1.67	1.02–2.73	1.52	0.96–2.39

[a] Optimum Temperature = 34.7 C (66th percentile), 1st percentile = 10.9 C, 2.5th percentile = 12.3 C, 97.5th percentile = 41.6 C, 99th percentile = 42.7 C.
[b] Defined as the temperature associated with the minimum mortality from the overall cumulative DLNM function.
[c] Models were adjusted for relative humidity, seasonality, and day of the week.

Table 3
Relative risks of death for hot and cold temperatures at selected cut points in the distribution of lags.

	Heat effect (99th vs optimum)[a]		Cold effect (1st vs optimum)[a]	
Lag (days)[b]	RR	95% CI	RR	95% CI
0 (immediate effect)	**1.06**	**1.02–1.10**	**1.08**	**1.03–1.13**
1	**1.05**	**1.02–1.08**	**1.07**	**1.03–1.11**
2	**1.04**	**1.01–1.07**	**1.06**	**1.03–1.10**
3	**1.04**	**1.01–1.06**	**1.05**	**1.02–1.09**
5	**1.02**	**1.00–1.04**	**1.04**	**1.02–1.06**
6	**1.02**	**1.00–1.04**	**1.03**	**1.01–1.06**
7	**1.01**	**1.00–1.03**	**1.03**	**1.01–1.05**
8	1.01	0.99–1.03	**1.02**	**1.00–1.04**
9	1.01	0.99–1.02	**1.02**	**1.00–1.04**
10	1.00	0.99–1.02	1.01	0.99–1.04
15	1.00	0.98–1.02	1.00	0.98–1.02
20	1.01	0.99–1.02	1.00	0.98–1.02
25	**1.02**	**1.00–1.04**	1.00	0.98–1.02
30	**1.03**	**1.00–1.06**	1.01	0.97–1.04

Values in bold are estimates that are statistically significant at alpha level of 0.05.
[a] Optimum = 34.7 C (66th percentile); 1st percentile = 10.9 C; 99th percentile = 42.7 C.
[b] Models were adjusted for relative humidity, PM10, ozone, seasonality, and day of the week.

We further examinated the dose response curves using 3 slices of the three-dimensional plot at specific lag times (Fig. 4). The shape of temperature and death curves changed at different lag points. The dose response curve was most pronounced at lag 0 showing a V-shaped relationship with no clear threshold effect. At lag 9, only the cold temperatures showed a weak significant association.

4. Discussion

In this study, we found that high and low ambient temperatures were significantly associated with increased short-term risk of mortality in Kuwait. The relationship between temperature and mortality was non-linear and no threshold effect was seen. Primary air quality measures, namely PM_{10} and ozone, did not have a confounding effect. To the best of our knowledge, this is the first study of its kind to explore the relationship between temperatures and mortality in Kuwait, and the Gulf Region. This study also provides an insight into temperature-related mortality in inherently hot and arid regions.

Increased risk of death due to high temperatures is widely supported in the literature, but the strength of the association has always been dependent on geography, climate, and study populations (Gasparrini et al., 2015; Basu, 2009). Some researchers have presented higher vulnerability to heat in cold regions (Curriero et al., 2002; Chung et al., 2009), and others showed evidence of acclimatization (Zanobetti and Schwartz, 2008; Anderson and Bell, 2009). Also, the use of air conditioners is considered protective against heat-related mortality (O'Neill et al., 2005b, 2003). Kuwait is a prosperous country; air conditioners are thought to be abundant and heavily used throughout the year (Al-Azmi et al., 2008). Despite having much higher temperatures in Kuwait compared to other locations, the difference in the magnitude of heat effects may be explained by acclimatization, use of air conditioners, and other adaptive behaviors (staying indoors, choice of clothing, etc.). Because of the limitation of our data, we were not able to control for the use of air conditioners in Kuwait.

We found that the increase in hot temperatures at lag 0 produced the highest risks of death in Kuwait. This is in line with many prior studies (Anderson and Bell 2009; Medina-Ramón and Schwartz, 2007; Zanobetti and Schwartz, 2008). However, our findings also showed a statistically significant re-increase of mortality risk at very long lag times (25–30 days). Further flexible modeling using natural splines

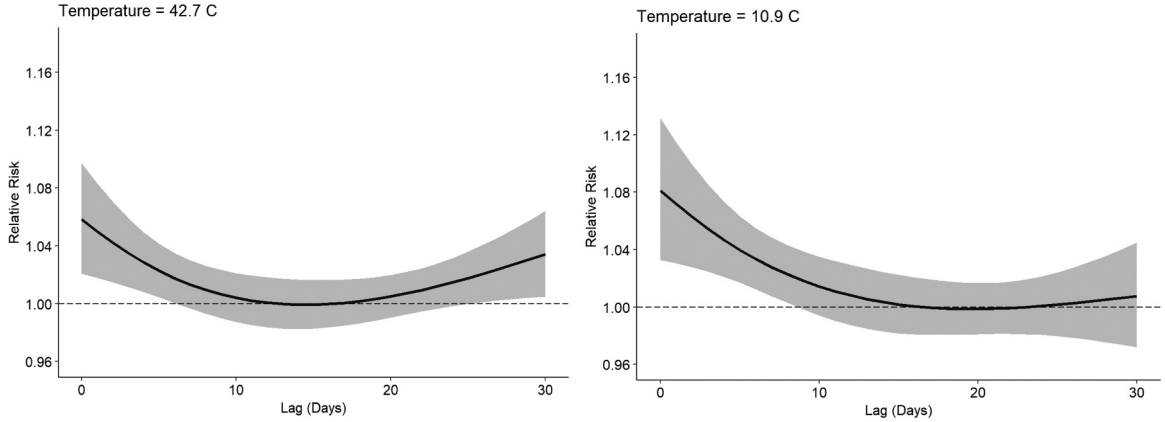

Fig. 3. The estimated hot (left) and cold (right) temperature effects on mortality vs. lag days using DLNM (the shaded areas are 95% confidence intervals).

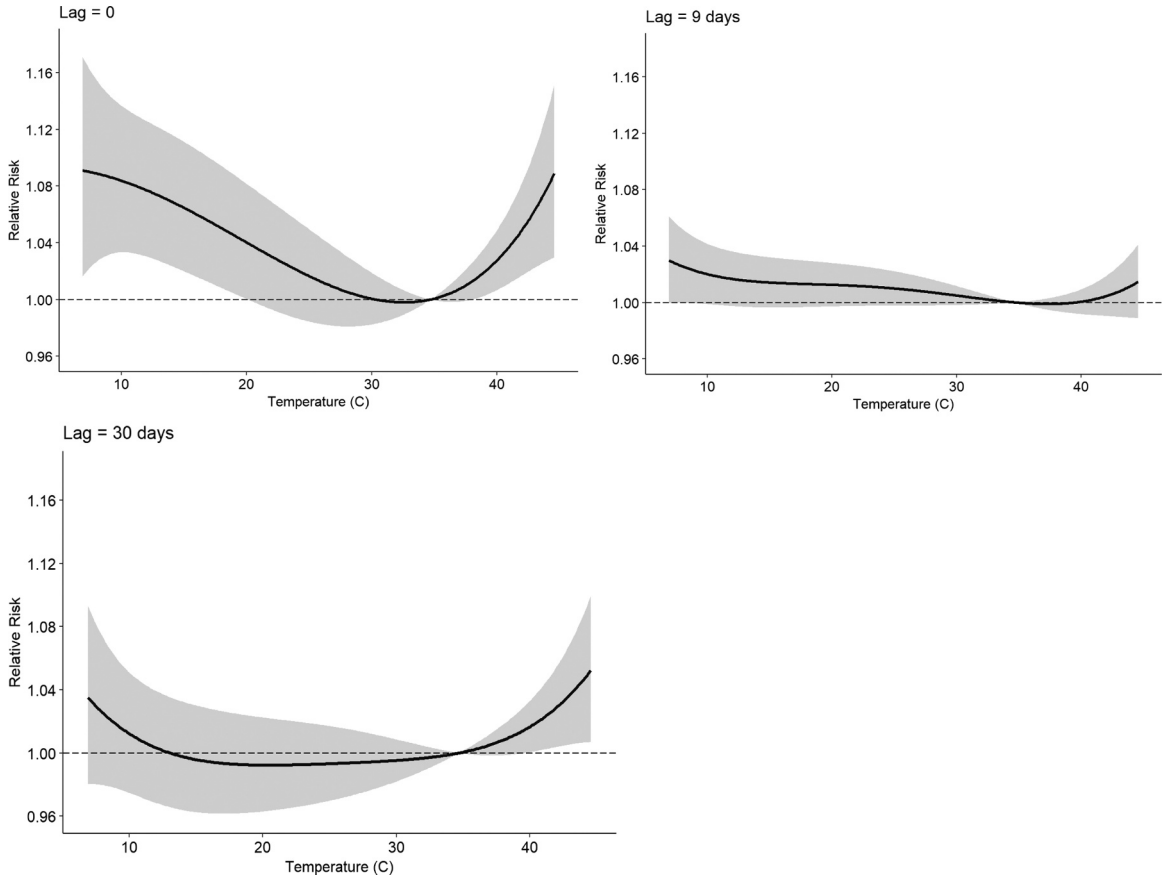

Fig. 4. The estimated effects of temperatures on mortality at selected lag times, lag 0, lag 9, lag 30 using DLNM (the shaded areas are 95% confidence intervals).

with different degrees of freedom did not change this late heat effect. This is an unusual finding and inconsistent with most of the literature from European North-Continental cities, and North American cities that show a very short lag effect of hot temperature. However, Baccini et al. (2008) showed that Mediterranean European cities experienced a similar late re-increase of mortality in hot temperature effects (although it was not statistically significant). There may be some possible explanations for this finding. The reduction in the middle lag periods may be related to the harvesting or frailty effect where those who are the most susceptible die earlier in the period and those who are relatively more resilient remain (Toulemon and Barbieri, 2008). Harvesting effects, varying seasonal susceptibility to temperature, or a change in acclimatization behavior may be considered to explain this finding of reduction then increase in mortality with longer time frames (Gasparrini et al., 2016). Further investigation is needed to properly understand this finding.

The association between cold temperatures and risk of death has been reported widely (Curriero et al., 2002; Keatinge and Donaldson, 1997; Anderson and Bell, 2009; Analitis et al., 2008). In the US, many studies reported significant lag effects between 2 and 5 days (Barnett et al., 2005; Medina-Ramón and Schwartz, 2007; Kalkstein and Davis, 1989), but European studies consistently found that the lag effect of cold temperatures persisted for more than two weeks (Analitis et al., 2008; Pattenden et al., 2003). We found that the cold lag effects in Kuwait were significantly present for up to 9 days and no significant re-increase with very long lag times. In previous studies conducted in hot and humid cities in Florida, US (Miami, Jacksonville, and Tampa) investigators used shorter lag structures to model cold effects (Curriero et al., 2002; Kinney et al., 2015). Meanwhile, in studies done in other subtropical areas (e.g. Beirut, Lebanon, and Zhuhai, China), longer lags of more than 20 days for cold effects were found to be significant (El-Zein et al., 2004; Wu et al., 2013). We were not able to identify studies on effects of low temperatures in arid or hyper-arid hot regions with similar weather of Kuwait.

The magnitude of cold effects was slightly higher than hot effects in Kuwait, although not significantly different. Cold vulnerability is a common finding among hot regions in the literature, which could be partly due to lack of adaptation to colder temperatures and the high incidence of respiratory infections in winter (e.g., influenza). Infectious diseases may have accounted for the cold effects in our study, and we were not able to control for that.

Our findings suggest that the relationship between high and low ambient temperatures and mortality was not confounded by the selected air pollution metrics. In the literature, the debate on air pollution as a confounder to the temperature-related mortality has yet to be settled. Some studies have suggested that ozone and PM are potential confounders and effect modifiers (Son et al., 2011; O'Neill et al., 2005a; Vaneckova et al., 2008). One study showed that ozone concentrations were a significant confounder during hot temperature days (Ren et al., 2008). Others did not find a significant effect modification or confounding by PM and ozone (Zanobetti and Schwartz, 2008; Stafoggia et al., 2006; Goldberg et al., 2011). This work adds to the existing literature on air quality adjustment to the temperature-mortality relationship. But, our PM_{10} data showed high variability and extreme outliers. This skewness may indicate a measurement error that is likely to be due to the high frequency of dust storms and resuspension of dust particles (Alolayan et al., 2013). The quality of the PM data may have affected our conclusion.

In this study, we established a non-linear dose-response relationship between ambient temperatures and short-term mortality risk in Kuwait. The curve was approximately V-shaped at shorter lags, with no evidence of a threshold. Using distributed lag non-linear models gave a smooth function to the relationship and did not force a specific shape of the curve. Using time-series design for temperature-outcome

relationships can be efficient to create projections that can predict the effects of climate change under different emissions scenarios (Huang et al., 2011). This can be informative in deriving quantitative risk assessment models of climate change effects in the region. Ahmadalipour & Moradkhani (2018) used projection models under future emission scenarios (RCP 4.5 and 8.5), both showed excessive relative risks of death from heat in the Arabian Peninsula. Under business-as-usual scenario (RCP 8.5), human habitability is likely to be severely impacted by high temperatures in this part of the world (Pal and Eltahir, 2016). We present supporting evidence from the current available data in Kuwait. The evidence can inform policymakers in the country on the importance of climate change adaptation to limit the effects of extreme temperatures.

The estimation of this dose-response relationship is associated with some uncertainties. Firstly, we used ambient temperatures as a surrogate for individual exposure. We do not know the extent to which ambient temperatures correlate to micro-environmental temperatures, which are likely to be affected by adaptive mechanisms like usage of air conditioners (Medina-Ramón and Schwartz, 2007). Secondly, extrapolating our results beyond the observed data range may fail to capture potential non-linear increases in risk especially with possible high intensity, duration, and spatial context of heatwaves in the future (Gasparrini et al., 2017). Both uncertainties may result in underestimation of the temperature-related mortality.

We did not investigate effects on individual characteristics and susceptible subgroups, these include gender, age group, cause of death, nationality, and socioeconomic variables. Previous studies have shown that these variables are likely to be effect modifiers (O'Neill et al., 2003; Medina-Ramón et al., 2006; Son et al., 2011; Goldberg et al., 2011). We were not able to test for spatial confounding or effect measure modification by geographic location in Kuwait because of the limitation of our mortality data. However, previous studies in Kuwait showed no notable spatial variability between temperature monitoring stations (Nasrallah et al., 1990, 2004). In our data, the daily temperatures were highly correlated between the stations and we did not find evidence of high variability between stations in our descriptive analyses (supplementary material). Also, we were not able to find data on $PM_{2.5}$, which may be a better risk predictor than PM_{10}, especially among patients with cardiovascular disease (Bhaskaran et al., 2009). Since our PM_{10} data was not optimal, we cannot exclude residual confounding by particulate matter.

5. Conclusion

In conclusion, we showed that there is a statistically significant positive relationship between high and low ambient temperatures and short-term mortality risk in Kuwait. This is a promising initial work in Kuwait, and may also be informative for the broader Gulf Region and the Middle East. More climate change vulnerability and risk assessments are encouraged in this region to inform decision-makers on the necessity of mitigation and adaptation to global environmental challenges.

CRediT authorship contribution statement

Barrak Alahmad: Conceptualization, Methodology, Writing - original draft. **Ahmed Shakarchi:** Data curation, Methodology, Software, Formal analysis. **Mohammad Alseaidan:** Methodology, Writing - review & editing. **Mary Fox:** Conceptualization, Writing - review & editing, Supervision.

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Declarations of interest

None

Ethics in publishing

The work described in this article has been carried out in accordance with *The Code of Ethics of the World Medical Association (Declaration of Helsinki)*

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envres.2019.01.029.

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